AFRL-AFOSR-VA-TR-2015-0281

Nonlinear Multidimensional Assignment Problems Efficient Conic Optimization Methods and Applications

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06/24/2015
Final Report

Air Force Research Laboratory
AF Office Of Scientific Research (AFOSR)/ RTA2
Arlington, Virginia 22203
Air Force Materiel Command

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
29-06-2015	Final	April 2012 - March 2015

4. TITLE AND SUBTITLE
Nonlinear Multidimensional Assignment Problems
Efficient Conic Optimization Methods and Applications

5a. CONTRACT NUMBER

5b. GRANT NUMBER
FA9550-12-1-0153

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Mittelmann, Hans D

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Arizona State University
School of Mathematical & Statistical Sciences
901 S. Palm Walk (P.O. Box 871804)
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8. PERFORMING ORGANIZATION REPORT NUMBER
TKS0174

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Arizona State University
Office of Research and Sponsored Projects Administration
660 S. Mill STE 312
Tempe, Arizona 85281-3670

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
025445-001

12. DISTRIBUTION/AVAILABILITY STATEMENT
DISTRIBUTION A

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The major goals of this project were completed: the exact solution of previously unsolved challenging combinatorial optimization problems. The size 16 three-dimensional quadratic assignment problem Q3AP from wireless communications was solved using a sophisticated approach with orbital shrinking and other techniques to exploit its symmetry. This problem has complexity (16!)^2 which is about 4.4*10^26. Another combinatorial optimization problem, the Directional Sensor Problem, was solved in two ways. First, heuristically in an engineering fashion and second, exactly after convexification. This had not been done before. While the Q3AP was solved in a linearized form leveraging the power of available MILP solvers, the sensor problem was solved as a nonlinear MINLP problem. Specifically, the information gain obtained was maximized in order to determine the optimal placement of the sensors. However, available MINLP solvers are not sufficiently effective, even in the convex case, and a hybrid Benders decomposition method was developed and applied. Results were published or submitted for publication and presented at several international conferences and a large number of research centers and universities around the world.

15. SUBJECT TERMS
combinatorial optimization, quadratic assignment, wirelesss communications, directional sensors, convexification, linearization, hybrid Benders decomposition

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Third Annual and Final Report on AFOSR grant FA9550-12-1-0153

PI Hans Mittelmann, Arizona State University

In the second half of the grant period an emphasis was put on **distributing** the results of our funded research.

In 2014 we went on an extended travel to Australia and gave talks at the following universities:

- University of Newcastle, Newcastle, NSW
- University of New South Wales, Sydney, NSW
- Federation University, Ballarat, VIC
- University of Melbourne, VIC
- Curtin University, Perth, WA
- Flinders University, Adelaide, SA

Later in the same year we gave talks in Europe

- Aalto University, Helsinki, Finland
- Abo Akademi University, Turku, Finland
- Institute of Scientific Computing, University of Heidelberg, Germany
- Technical University Munich, Munich, Germany
- University of Erlangen-Nuremberg, Erlangen, Germany
- ZIB, Zuse Institute for Informatics, Berlin, Germany

We further gave talks in 2014 at the conferences

- Conference on PDEs; Novacella, Italy
- INFORMS Annual Meeting, San Franciso, CA

In early 2015 we went on an extended SE Asia trip and gave presentations at

- Chinese University of Hong Kong
- Hong Kong University of Science and Technology
- National Taiwan Normal University, Taipei, Taiwan
- National Taiwan University, Taipei, Taiwan

We further gave a talk at the conference **High Performance Scientific Computing 2015** in Hanoi, Vietnam.

All this in addition to numerous presentations earlier in the grant period, not listed here.

The final year of the grant period saw the attempt to address a number of challenging problems building on the earlier research and with the expectation that only a few could be finished within the grant period and most would have to be continued under a future grant. These problems include the exact solution of larger Q3AP problems and of still larger QAP problems.

An emphasis was here to avoid academic problems and instead work on real-life engineering problems. Some of these challenges were elusive on this first attempt, others ware successful close to the end of the grant period.

The paper [1] had addressed a very specific three-dimensional assignment problem from wireless communications. This problem had been developed by the electrical communications engineer Zhi Ding, UC Davis, and his former student Harvind Samra. Peter Hahn et al [7] had attacked the problem for 8 and 16 bit assignments. they were only able to solve the smaller case exactly. Then in [1] we were able to do this for the size 16 problem, a **major** accomplishment. However, the modulation used in this work was special and in practice one often considers other methods. The modulation in [1] is phase-shift keying or PSK while in practice quadrature amplitude modulation or QAM is preferred. Further, there are several types of transmission channels in use. We collaborated with Zhi Ding and his current student Wenhao Wu and considered Q3AP problems for QAM modulation and sizes up to 64.

A first publication [5] addresses the 16 bit modulation Q3AP but for various channels. Our approach is to use the heuristic already successfully utilized in [1]. As can be seen from various graphs, our results are the best in a comparison with those of other typical methods.

However, an engineering ad hoc method (Seddik), came close in quality for this rather small bit number. In practice more frequently 32 and 64 bits are used. Since exact solution for size 32 is at present out of the range of computational power, we used heuristics again to solve realistic problems of these larger sizes through a sequence of two-dimensional QAPs, see [6].

As the graphs in [6] show, our method is giving by far the best results. The papers [5,6] will be finished in the near future.

While the number of publications produced in the grant period is moderate, the quality is partially substantial. Another reason is our delayed start due to vision problems during the entire year 2012 (5 eye surgeries up until late December).

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[1] H. D. Mittelmann and D. Salvagnin, Exact and Heuristic Approaches for Directional Sensor Control, submitted, http://www.optimization-online.org/DB_FILE//2013/08/4016.pdf

[2] R. Shankar, H. D. Mittelmann, and E. K. P. Chong, Directional Sensor Control for Maximizing Information Gain, Proc. SPIE 8857, Signal and Data Processing of Small Targets 2013, 88570J (September 30, 2013); doi:10.1117/12.2022451

[3] R. Shankar, H. D. Mittelmann, and E. K. P. Chong, Directional Sensor Control: Heuristic Approaches, IEEE Sensors Journal 15(1), 374-381 (2014)

[4] H. D. Mittelmann and D. Salvagnin, On Solving a Hard Quadratic 3-Dimensional Assignment Problem, Mathem. Progr. Computat. 7(2), 219-234 (2015), doi: 10.1007/s12532-015-0077-3

[5] W. Wu, H. Mittelmann, and Zhi Ding, Modulation Diversity Design in Cooperative Relay-HARQ Network, in preparation

[6] W. Wu, H. Mittelmann, and Zhi Ding, Modulation Diversity Design in Amplify-and-Forward Two-Way Relay HARQ Network, in preparation

[7] P. Hahn, B-J Kim, Th. Stuetzle, S. Kanthak, W.L. Hightower, H. Samra, Z. Ding, and M. Guignard: The quadratic three-dimensional assignment problem: Exact and approximate solution methods. EJOR 184, 416-428 (2008)

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Grant/Contract Title
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Efficient Conic Optimization Methods and Applications

Grant/Contract Number
AFOSR assigned control number. It must begin with "FA9550" or "F49620" or "FA2386".

FA9550-12-1-0153

Principal Investigator Name
The full name of the principal investigator on the grant or contract.

Hans Mittelmann

Program Manager
The AFOSR Program Manager currently assigned to the award

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Reporting Period Start Date

04/01/2012

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Abstract

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